HEAVY ION PHYSICS WITH THE ALICE EXPERIMENT AT LHC

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ALICE is the experiment at the LHC collider at CERN dedicated to heavy ion physics. In this report, the ALICE detector will be presented, together with its expected performance as far as some selected physics topics are concerned.

1 Introduction

Besides its proton-proton (pp) physics program, the Large Hadron Collider at CERN, which is going to start operating in early 2008, will deliver lead-lead (PbPb) collisions at a centre-of-mass energy $\sqrt{s_{NN}}$ = 5.5 TeV, opening the door to unexplored regimes in heavy-ion particle physics from several points of view, such as the centre-of-mass energy, the energy density reached, the lifetime and the volume of the Quark-Gluon Plasma (QGP) system which may be created in the collision. ALICE (A Large Ion Collider Experiment) will be the experiment dedicated to study heavy-ion collisions at the LHC. Its physics program will span over a large number of observables, from the global properties of the collisions (multiplicities, rapidity distributions...), to more selective QGP signals (like direct photons, charmonium and bottomonium...). In this report, an overview of the LHC and the ALICE detector will be first provided. Then, the physics performance of the experiment as far as open charm and open beauty detection, quarkonia and jet physics studies will be discussed. Finally, the ALICE "First Day" Physics will be briefly presented.

2 The ALICE Experiment at the LHC

The Large Hadron Collider experimental program will deal with different collision systems. Apart from the main pp and PbPb runs, also asymmetric collisions (such as p-Pb) and collisions with heavy ions other than Pb (e.g. Ar) will be studied. Table 1 quotes the expected values for the most significant running parameters for the pp and PbPb collision systems, which have been used as a reference for the results presented hereafter.

ALICE will be the experiment at the LHC dedicated to heavy-ion physics. In the central rapidity region $-0.9 < \eta < 0.9$, inside the L3 magnet (providing the experiment with a weak solenoidal magnetic field B = 0.2 - 0.5 T), ALICE will be endowed with subdetectors specialized in tracking and identifying the particles produced in the collisions, namely the ITS (Inner Tracking System), the TPC (Time Projection Chamber), the Transition Radiation Detector (TRD), and the Time Of Flight (TOF). The central region will be also equipped with two detectors having partial azimuthal coverage: the HMPID (High Momentum Particle Identification Detector) and the PHOS (Photon Spectrometer). Besides, an Elecromagnetic Calorimeter (EMCAL) has recently been added to the ALICE central setup, covering the pseudorapidity range $|\eta| < 0.7$ and 110° in azimuth [1]. To be noted that, due to the late inclusion of the EMCAL in the ALICE design, its installation will be slightly delayed with respect to the other central detectors. In the pseudorapidity region $-4.0 < \eta < -2.5$, instead, the ALICE Muon Spectometer will be the detector encharged of studying both heavy quark vector mesons and the ϕ meson via the $\mu^+\mu^-$ decay channel, and the production of open heavy flavours. At large rapidity values, other detectors will be installed, namely the Zero Degree Calorimeter (ZDC), the Photon Multiplicity Detector (PMD), the Forward Multiplicity Detector (FMD) and the V0 and T0 detectors. Finally, the ALICE triggering on cosmic rays will be performed by the ACORDE detector (for more details see [2]).

Table 1: LHC expected running conditions for pp and PbPb collisions. Due to the limited ALICE rate capability, in the experiment interaction region a lower pp luminosity value is foreseen (quoted within brakets in the first row, third column of the Table).

Collision System	$\sqrt{s_{\mathrm{NN}}}$ (TeV)	L_0 ($\mathrm{cm}^{-2}\mathrm{s}^{-1}$)	Run Time (s/year)	σ_{geom} (b)
pp	14.0	10^{34} (10^{31})	10^7	0.07
PbPb	5.5	10^{27}	10^6	7.7

3 ALICE Physics Performance

The ALICE experiment will study a wide number of observables, which will require the use of variuos experimental techinques[3]. In the following, the ALICE expected performance in terms of measurement of heavy flavour (Sect. 3.1), quarkonia (Sect. 3.2) and jet production (Sect. 3.3) will be briefly overviewed.

3.1 Heavy Flavour Production in the Central Detectors

Due to their high mass, heavy flavour quarks (charm and beauty) are produced at the very early stage of the collision. For this reason, the measurement of open charm and open beauty production is one of the main observables which can trace the initial phase of the collision and provide information on the possible formation of the Quark Gluon Plasma. Experimentally, the effects of medium modifications on the final states have shown up in the parton energy loss observed in AA collisions at RHIC, where a departure from binary scaling not only for light charged hadrons, but also for heavy flavour production (for "non-photonic electrons", in fact, which are likely to come from heavy flavour decays) has been observed[4].

At the LHC, detailed studies on heavy flavour production will be even more feasible compared to RHIC, thanks to the high expected yields for open charm and open beauty, which are expected to be of the order of ~ 100 $\mathrm{c\bar{c}}$ and ~ 5 $\mathrm{b\bar{b}}$ in a central PbPb collision[a]. To be noted that these analyses will be important also because they will be used as a reference for quarkonia production studies (see Sec. 3.2).

The open charm and open beauty analysis will rely on the capabilities of the ALICE vertex detector, the ITS, which will be characterized by a resolution on the measurement of the track impact parameter better than 100 μm for $\mathrm{p_T} > 0.6$ GeV/c, allowing to fully reconstruct heavy flavour decays. The tracking and the momentum measurement will be provided by the TPC detector, while particle identification will be performed by the TOF detector in the case of charged hadrons, and by the TRD and the TPC in the case of electrons. As an example of the ALICE performance in measuring open charm, the left panel of figure 1 shows the $\mathrm{K}\pi$ invariant mass distribution for the study of the $\mathrm{D} \rightarrow \mathrm{K}^-\pi^+$ channel, as obtained for 10^7 PbPb central events[b].

Being able to measure separately charm and beauty hadrons will offer ALICE the opportunity to study the dependence of the energy loss on the mass of the heavy parton. Besides, the heavy-to-light ratio $R_{\mathrm{D/h}}(\mathrm{p_T})$, defined as the ratio of the nuclear modification factor of D mesons to that of charged light-flavoured hadrons, will allow to shed light on the colour-charge dependence of QCD energy loss. For more details on open charm and open beauty analyses with the ALICE detector, see[3].

[a] The quoted values for the open charm and open beauty production rate have been computed taking into account also the shadowing effect.

[b] The centrality class of an event has been determined according to the impact parameter b. In particular, the PbPb 5% most central events correspond to a selection on the event impact parameter $b < 3.5$ fm.

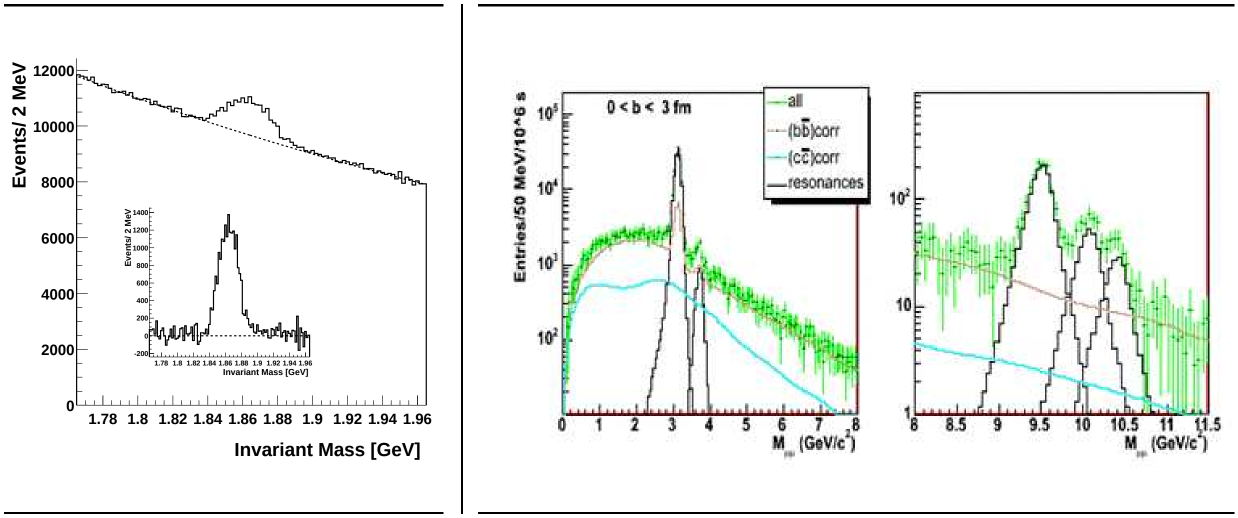

Figure 1: Left panel: Kπ invariant mass distribution for 10^7 PbPb 5% most central ($b < 3.5$ fm) events. The same distribution after background subtraction is shown in the inset. Right panel: expected ALICE performance for the dimuon spectrum measurement for charmonium (left) and bottomonium (right) for a 10^6s PbPb run (5% most central events). The uncorrelated combinatorial background has been subtracted.

3.2 Quarkonia

The study of quarkonia production in heavy ion collision is one of the main observables which can be used to investigate the properties of the medium created in the collision. As a matter of fact, quarkonia are expected to be sensitive to the collision dynamics (both at short and long timescales) and to plasma formation. Moreover, since different quarkonia disassociate at different temperatures, they can serve as a thermodynamic probe of the medium [5].

From an experimental point of view, the expected anomalous suppression of the J/Ψ related to Debye colour screening [6] observed at the CERN SPS [7] was thought to be even stronger at RHIC, even in case some dissociation mechanisms due to comoving hadrons would have occurred. Contrarily, the level of J/Ψ suppression was found to be the same as that at the SPS [8], which would imply the presence of some recombination effect [9] competing with the suppression one. As a consequence, at the LHC, because of the even higher $c\bar{c}$ rate, the regeneration mechanism is expected to dominate, so that an enhancement in the J/Ψ yield may even take place [10].

The measurement of quarkonia in ALICE will be performed both at midrapidity in the dielectron channel (making use of the ITS and TPC for tracking, and of the TRD for electron identification), and in the forward rapidity regions, where the ALICE Muon Arm will study the dimuon channel. This implies that the ALICE detector will be able to measure quarkonia production in two complementary Bjorken-x regions, allowing to investigate the PDFs in the nuclei. Moreover, the feed-down from B decays for J/Ψ production will be kept under control thanks to the open beauty measurements presented in Sec. 3.1.

The right panel of figure 1 shows the ALICE expected performance in a 10^6s PbPb run (5% most central events) for the measurement of the dimuon spectrum for charmonium (J/Ψ, left) and bottomonium (Υ, right). It has been shown [3] that for the J/Ψ the statistics collected during one PbPb data taking period will be enough to measure also the p_T dependence of the charmonium spectrum, while for the Υ case, because of the smaller statistics, either different centrality classes of events will have to be merged, or two or three data taking periods will be necessary. Finally, it is worth to mention that for quarkonia studies the sensitivity of the results to different suppression scenarios has been investigated. For more details, see [3].

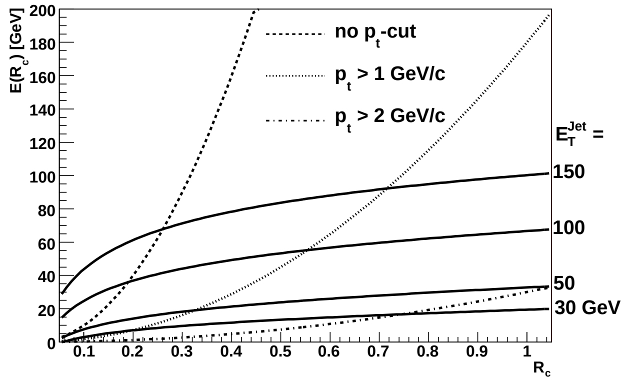

Figure 2: Charged jet energy within a cone of size R_c (full lines) compared to the energy of the underlying event (dashed lines), for different transverse momentum cuts. The background energy has been calculated using HIJING quenched with $b < 5$ fm.

3.3 Jet Physics

Proton-proton collisions at the LHC will be characterized by a very high jet production rate. On one hand, jets with energy larger than 20 GeV are expected to occur with a frequency of ~ 1 per PbPb central event; on the other, $\sim 10^5$ highly energetic jets with $E_T \sim 200$ GeV are expected to be produced in 10^6s of PbPb data taking. Thanks to their high transverse energy, it will be possible to single out and reconstruct these high energy jets on an event-by-event basis also in a very entangled environment as that produced in a PbPb event. Moreover, the addition of the Electromagnetic Calorimeter detector (EMCAL) in ALICE will improve the performance of the experiment in terms of jet physics, both at the level of energy measurement, and at the level of the high energy jet triggering capabilities of ALICE.

One of the main characteristics of ALICE jet reconstruction is that in order to keep under control as much as possible the background level, it will make use of a limited jet cone size, $R_c = \sqrt{(\Delta\eta)^2 + (\Delta\phi)^2} \sim 0.3 \div 0.4$. Moreover, appropriate p_T cuts will have to be applied, as shown in Figure 2. Here, the energy of the jet from charged particles as a function of the cone size R_c is drawn (for different energies). The background energy is also plotted for different transverse momentum thresholds, from 0 to 2 GeV/c. As one can see, while the background energy, which is proportional to R_c^2, can be reduced either reducing R_c, or by applying a p_T cut (or both), the signal energy is affected by these choices only to a minor extend.

4 ALICE "First Day" Physics

After the collider closure in late 2007, the first commissioning run at $\sqrt{s} = 900$ GeV is foreseen to occur at the beginning of 2008, when the ALICE setup will be characterized by the installation of the complete ITS, TPC, HMPID, Muon Arm, PMD, trigger detectors, and of partial configuration of the TOF, TRD and PHOS. Already with the first $\sim 10^4$ events collected during this run, some "First Day" Physics measurements will be feasible, namely the study of $dN/d\eta$ distributions, p_T spectra, multiplicity distributions, and baryon transport analysis.

To be noted that pp runs at both the commissioning energy $\sqrt{s} = 900$ GeV and at the full-energy $\sqrt{s} = 14$ TeV (in late 2008) will serve not only as a baseline for the future ALICE heavy-ion program, but will also be important by themselves. As a matter of fact, the excellent expected ALICE pp performance in terms of tracking and particle identification, especially in the low p_T range, will make it complementary to the other LHC proton-proton experiments.

5 Conclusions

The ALICE experiment is characterized by a remarkable versatility in terms of the observables it will look at, and of the experimental techniques it will make use of. As the first commissioning run scheduled for the beginning of 2008 is approaching, the ALICE installation and commissioning is underway, and the experiment is evaluating its physics reach with respect to a wide variety of topics. In this report, to give some examples of the ALICE expected performance, three selected observables have been discussed, namely heavy quarks, quarkonia and jet physics.

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References

1. ALICE Addendum to the Technical Proposal: Electromagnetic Calorimeter, CERN-LHCC-2006-014.
2. ALICE Collaboration, ALICE: Physics Performance Report Volume I (2003) CERN/LHCC 2003-049, Eds. F. Carminati et al. (ALICE Collaboration), J. Phys. G: Nucl. Part. Phys. 30 (2004) 1517.
3. ALICE Collaboration, ALICE: Physics Performance Report Volume II (2005) CERN/LHCC 2005-030, Eds. B. Alessandro et al. (ALICE Collaboration), J. Phys. G: Nucl. Part. Phys. 32 (2006) 1295.
4. S.S. Adler et al. (PHENIX Collaboration), Phys. Rev. Lett. 96 (2006) 032301;
   B.I. Abelev et al. (STAR Collaboration), nucl-ex/0607012.
5. H. Satz, J. Phys. G32 (2006) R25.
6. T. Matsui and H. Satz, Phys. Lett. B178 (1986) 416.
7. M.C. Abreu et al. (NA50 Collaboration) Phys. Lett. B410 (1997) 337.
8. A. Bickley (PHENIX Collaboration) nucl-ex/0701035.
9. P. Braun-Munzinger and J. Stachel, Nucl. Phys. A690 (2001) 119;
   R.L. Thews et al., Phys. Rev. C63 (2001) 054905;
   L. Grandchamp and R. Rapp, Nucl. Phys. A709 (2002) 415.
10. A. Andronic et al., nucl-th/0611023.